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o chance with the present invention, (30) Priority: 18.08.1998 US 135696

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microcomponent verent (54) Semiconductor micro-optical components and method for producing them [1600]

A method for fabricating a monolithic microoptical component. The construction of the micro-optical components is accomplished by using standard semiconductor fabrication techniques. The method comprises the steps of depositing an etch stop layer (44) onto a semiconductor substrate (42); depositing an optical component layer (46) onto the etch stop layer (44); coating the entire surface of the optical component layer with a photoresist material; applying a photoresist mask (50) to the photoresist material on the optical component layer (46); selectively etching away the optical component layer (46) to form at least one optical column (52); forming a pedestal (54) for each of the optical columns' (52) by selectively etching away the etch stop layer (44); and finally polishing each of the optical columns (52), thereby forming monolithic optical components (56). The method may optionally include the step of removing the photoresist mask from each of the optical columns prior to polishing the optical columns, as well as the step of depositing an antireflectivity coating onto each of the optical components. EMPODIMENT

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micro-optical system for use to carrows on that polition unionsation applications since the elargitess in vigurations conacts to ange, the const2dry of the granthy Serence Moore be are process whithe disclesioed. 🏏 3 nous entiret) et ministed in 🖒 📆 Diritidonic T structure. This reduct mproves afterment soluata Ser zeaestara V and the Contra decidence parentity one's ว-ฮาฮเ The present ary groups and the present are the present standard semici nductor labricadon teurm nu facture a monotithin more more

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Description

うならい C THE INVENTION

1. Field of the Invention

[0001] This invention relates generally to micro-optical components and, more particularly, to a method for producing monolithic micro-optical components using standard semiconductor fabrication techniques.

2. Discussion of the Related Art

Compact and simple lens systems for microoptical devices are essential in optical communication systems. Generally, an optical communication system is comprised of independently fabricated micro-optical components that are attached to microbenches. Present optical systems use a variety of techniques for fabricating micro-optical components and for obtaining efficient coupling between micro-optical components and other micro-optical devices. For instance, these optical systems might be manually assembled from very small parts by persons using tweezers and a microscope. Although this manual approach may be feasible for limited quantities of systems, difficulty remains in achieving high output production. On the other hand, current automated assembly techniques fail to achieve the precision alignment and quality needed for most microcomponent systems.

[0003] Therefore, it is desirable to provide a monolithic micro-optical system for use in various optical communication applications. Since there are less individual components to align, the complexity of the assembly process will be decreased. Some assembly steps are entirely eliminated with the formation of a monolithic structure. This reduction in assembly complexity improves alignment accuracy, increases reliability and decreases assembly costs for a micro-optical system. The present invention solves these problems by using standard semiconductor fabrication techniques to manufacture a monolithic micro-optical system.

SUMMARY OF THE INVENTION:

[0004] The present invention relates to a method for fabricating monolithic micro-optical components. The construction of the micro-optical components is accomplished by using standard semiconductor fabrication techniques. The method comprises, in one embodiment, the steps of depositing an etch stop layer onto a semiconductor substrate; depositing an optical component layer onto the etch stop layer; coating the entire surface of the optical component layer with a photoresist material; applying a photoresist mask to the photoresist material on the optical component layer; selectively etching away the optical component layer to form at least one optical column; forming a pedestal for

each of the optical columns by selectively etching away the etch stop layer; and finally polishing each of the optical columns, thereby forming monolithic optical components. The method may optionally include the step of removing the photoresist mask from each of the optical columns prior to polishing the optical columns, as well as the step of depositing an antireflectivity coating onto each of the optical components.

9.3894 FREE pattern notation of BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Other objectives and advantages of the present invention will be apparent to those skilled in the art upon reading the following detailed description and upon reference to the drawings in which the drawings in whi

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Figure 1 is a perspective view of a micro-optical system having a micro-optical component in accordance with the present invention;

Figure 2 is a top view of a micro-optical duplexer system implementing an exemplary micro-optical component of the present invention; and

Figure 3 is a side view illustration of a semiconductor wafer in accordance with the present invention;

Figure 4 is a top view illustration of a photoresist mask in accordance with the present invention;

Figure 5 is side view illustration of a photoresist mask in accordance with the present invention;

Figure 6 is side view illustration of initial optical columns being-formed by selectively etching away an optical component layer in accordance with the present invention;

Figure 7 is a side view illustration of pedestals.

being formed by an undercutting etching process in accordance with the present invention:

Figure 8 is a side view illustration of the selectively etched surface of the optical columns, where the photoresist mask has been removed in accordance with the present invention; and

Figure 9 is a side view illustration optical components that have been polished into shape in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0006] While the invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the invention is not limited thereto. Those having ordinary skill in the art and

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access to the teachings provided herein will recognize additional modifications, applications and embodiments within the scope thereof and additional fields in which the present invention would be of significant utility. [0007] A micro-optical system 10 for use in an optical system fiber network application is depicted in Figure 1. Microoptical system 10 is a monolithic structure that is created (as further described below) using standard semiconductor fabrication techniques. Micro-optical system 10 includes an micro-optical component 14 connected 10 by a pedestal 16 to a semiconductor substrate 12. The micro-optical component 14 is shown as a spherical ball... lens, but is intended to represent various optical components, such as a cylindrical or conical lens, a concave or convex lens, a prism or any, other related optical 15 devices. Each, of these components, or combinations thereof serve to focus light or redirect an optical beam between other photonic components (e.g., receivers, transmitters and repeaters) and may be used to construct a micro-optical system. Visual notising the first Mary 20 [0008]... A micro-optical duplexer 20 is depicted in Figure 2 as an exemplary implementation of a micro-optical system in an optical fiber network application. Microoptical duplexer 20, is being used as a bi-directional transceiver, in. a. fiber network, Micro-optical duplex 20, 25 includes a microbench 30 that is mounted onto a housing 22 (e.g., Kovar, housing) which has a feedthrough for a an optic fiber 24. A single-mode fiber 24 serves as the connection to a remote fiber network (not shown) A photo diode 26 and laser diode 28 are also mounted to 3,30 housing 22. The tolerances in positioning and fixing these active devices on housing 22 are on the order of (e.g., hydrc bronnic acid deionizggraim [0009] Microbench 30 (4mm x 14mm x 1mm) provides the various passive micro-optical components needed 35 by the system. A right spherical lens 32, a left spherical lens 34 and a wavelength filter,36 are each formed and passively aligned on microbench, 30. In order, to have a collimated laser beam for a distance of several millimeters, these spherical lenses have a diameter on the 1040 order of 900 um To achieve the high accuracy that is required for this passive alignment, microbench 30, not including these micro-optical components are afabricated in accordance with the principles of the present on invention to the earl optical component has been formoitheuni [0010] in operation of the duplexer 20, light with the co wavelength = 1300 nm is emitted from laser diode 28 of and collimated by right spherical lens 32 before being and passed through wavefilter 36 and focused onto the end face of the single-mode fiber 24: Light, with the wave-16/50 length = 1550 nm enters through fiber 24 and is collimated by left spherical lens 34 prior to being reflected at the wavelength, filter, 36, and detected by photo diode, 26. While depicting these micro-optical components in the context of a micro-optical duplexer, ithis, discussion is at 55 intended, to adequately teach one skilled in the art to oc. implement micro-optical, components, of the present invention in a variety of optical applications, the entire believe

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[0011] Figures 3-9 illustrate the steps for fabricating a., micro-optical component of the present invention. Figure 3 shows a side view of a typical semiconductor wafer 40. Commonly known epitaxy techniques (i.e., LPE, MOCVD, etc.) are used to grow precisely calibrated thin single-crystal semiconductor layers. An indium phosphide (InP) substrate 42 serves as a microbench, for the micro-optical components. A pedestal layer 44 with a thickness on the order of 2-5 microns is deposited onto substrate 42. This layer is comprised -.. of a ternary material (i.e. InGaAs or AllnAs) quaternary material (ie., InGaAsP), and determines the pedestal height for each optical component. Using the accuracy... of the epi-crystal growth technology, the pedestal height can be controlled at the angstroms tolerance level. Any optical component layer, 46 is then deposited onto pedestal layer 44. Optical component layer 46 should be deposited at a thickness correlating to the maximum required lens dimensions (at least 20 microns thick). Indium phosphide (InP) is also chosen for optical comon ponent layer 46 because of its etching characteristics as well as its ability to form a high index lens with low aberinitial optical delumna 32 are shown in Figure 6. As was [0012] In an alternative preferred embodiment, the optical component layer, 46, and substrate, 42 may be comprised of gallium arsenide (GaAs), whereas the pedestal layer, 44 is comprised of aluminum gallium on arsenide (AlGaAs), It is important to note that other that materials can be used for these various layers. For example, the optical component layer 46 and substrate 42 may be any III-V semiconductor material and mayour include indium phosphide (InP), gallium arsenide, vo (GaAs), indium arsenide (InAs) and gallium phosphide bou (GaP). Moreover, although two different materials have ing similar thermal expansion coefficients may be used, the same material is preferably used for both optical, to component layer 46 and microbench substrate 42. slnggi this way optical alignment problems caused by thermal, expansion are minimized in optical applications where wide temperature variations are common (i.e., in milials, tary and space applications). or bayone deviate at 44 is selectively [0013] ... Photolithography and other known wafer fabrication techniques are then used to fabricate the optical components. First, a photoresist coating is applied over the the entire surface of the optical component layer 46% The preferred photoresist material is 2-ethoxpyethylace-ioc tate (60%) and n-butyl acetate (5%) in xylene; and hex-100; amethyldisilozane (HDMS) because of its suitability for too use in the dry, etching of deep profiles on indium phosphide (InP) and related semiconductor materials. Pho-HC toresist material may also include 2-ethoxyethylacetate) + n-butyl acetate in xylene solvent, 2-ethoxyethylace tate + n-butyl acetatenin xylene, and silicon dioxide (SiO₂) precoated, 2-ethoxyethylacetate: +(n-butyl ace-; 5v/ tate in xylene and silicon nitride (Si₃N₄) precoated silizing con dioxide (SiO₂) and complex silicon, nitride (Si₂N₂); the or aluminum oxide (Al₂O₃) precoated suffermed be a roll pro-[0014]: A-mask is used to transfer a lens pattern onto us:

the optical component layer. Lens patterns are chosen based on the quantity and type of lens required for a particular optical application. As will be apparent to one skilled in the art, an initial lens shape is dependent on the particular mask design. Depending on the type of optical component (e.g., spherical ball lens, cylindrical ball lens, conical ball lens, convex lens, concave lens, prism, or a combination of these components), a corresponding mask will be used to establish the shape of the initial optical column. As best seen in Figure 4, a 10 mask is a pattern in which the regions to be exposed are opaque and the protected regions are shaded. The mask is aligned with optical component layer 46 such " that when the photoresist material is exposed to an ultraviolet (UV) light source through the mask, the appropriate lens pattern is transferred onto the surface of the optical component layer. As a result, a photoresist mask 50, fas illustrated in Figure 5, is formed on the surface of optical component layer 46 plans the laner become [0015] Next, initial optical columns for each of the micro-optical components is formed by dry etching away the unwanted optical component material. These initial optical columns 52 are shown in Figure 6. As will be apparent to one skilled in the art, electron cyclotron resonance (ECR) etching, inductive couple plasma 25 (ICP) etching or reactive ion etching (RIE) are commonly employed dry etching techniques. Dry etch mixtures may include argon and hydrochloric acid (Ar/HCI), argon hydrogen and chlorine (AR/Cl₂/H₂), argon and hydrobromic acid (Ar/HBr), argon and bromine (Ar/Br2), 4 30 argon and chlorine (Ar/Cl2), argon and methane and hydrogen (Ar/CH₄/H₂), methyl iodide (H₃Cl); bromine iodide (IBr), methane and hydrogen and sulfur fluoride (CH//Ha/SFa) a fethyl iodide (CaHal), i isoethyl iodide (C₃H₇I). hexaflüoride carbon and hydrogen(C₂F₆/H₂), 35 or dichlorodifluoro carbon and oxygen (CCIaFa/Oa). [0016] Referring to Figure 7, wet selective etching with controlled undercutting will provide a pedestal support or stem 54 for each of these optical columns. By using a -> selective (quaternary) etching solution, pedestal layer 40 44 is selectively removed from underneath the optical columns without effecting the binary or other material" comprising the optical columns and substrate layer. Moreover this undercutting etching approach provides sufficient space below each of the optical columns for 45 polishing and subsequent formation of the optical components. Wet selective etching chemicals may include potassium hydroxide:potassium ferricyanide:deionized water (KOH: K3Fe(CN)₆: H₂O); lactic acid: nitric acid (10 lactic CH3CH2OCOOH:HNO3) hydrochloric acid:nitric acid (HCI:m:HNO39 where n>5) phosphoric acid:hydrogen peroxide:deionized water (HaPOa:HaO2: 81-HaO), nitric acid (HNO3); sulfuric acid:hydrogen peroxide:deionized water05 \(H2SO4:H2O2:H2O); (*Chitric 12 acid:tartaric 1 acid:deionized and (4/4,20) abin/water and consumention (notices HNO3:HOOC(CH5O)5COOH:H5O? where in between 1 and 10) and hydrofluoric acid:hydrogen peroxide:deionized water (HF:H2O2:n H2O) wherein between 1 and

20) ambober this method behisport of income on otherson. [0017] After the above-described etching process, the photoresist coating is removed from the optical component layer in Figure 8. Using acetone, the photoresist mask is removed from the surface of the optical columns. Following the removal of the photoresist mask, the acetone is removed from the surface of the optical columns with isopropanol and then the isopropanol is removed from the surface of the optical columns using deionized water. The photoresist can also be removed using photoresist stripper, potassium hydroxide, or other equivalent alkaline chemicals followed by a delonized water rinse. Finally, oxides and photoresist residues are removed from the surface of the optical columns using potassium hydroxide (KOH). [0018] Lastly, these optical columns are further etched and polished into optical components 56 as seen in Fig-19 ure 9. A selective wet etching process continues the formation process of an optical component For instance) a weak non-orientation binary selective etching solution (e.g., hydrofloric acid:hydrobromic acid (1HF:10HBr); hydrobromic lacid: acetic lacid lo (HBr: CH3COOH) e or hydrochloric citabilinas acidipropylene acidipropylene acidipropylene (HCI:CH3CHOHCH2OH)) can be used to polish and round off the edges and corners of the optical column. Since this solution will eith the corners and edges faster than other portions of the optical columns, the corners are rounded off to form lenses, thereby shaping the optical columns into optical components it should also be noted that this solution should not etch the quaternary material of the pedestals on palaret for lairness on palaret for the pedestals on the tolerances on palaret for the pedestals of the pedestal of the pedestals of the pedestals of the pedestal of the pedes [0019] Furthermore, a weak chemical polishing solution (e.g., hydrobromic acid:acetic acid:deionized. water(n HBr:CH3COOH:H20, Where n between and 4). Proof Shydrochiloric soll acid propylenesa sallycol (HCI:CH3CHOHCH2OH)) can be used to polish the surfaces of an optical column? In this case, polishing is usually performed at a very tow temperature, typically as between 10 degrees and 20 degrees centigrade! To polish the surface of of optical lens, emerge the water which contains the formed lens into the polishing solu P tion, agitate the wafer for a calibrated period of time and then rinse in deionized water. Allow water to dry before proceeding to the remaining steps tiw eans because in beas. [0020] Once an optical component has been for med. Town an antireflectivity or filtering coating can also be applied to any one of these optical components to maximize transmitted light. For the present invention, afterystal mixture of antireflectivity (AR) coating which contains magnesium fluoride (MgF), aluminum oxide (Al2O3), and hafnium fluoride (HfF), silicon dioxide (SiO₂), and silicon nitride (SiaNa) is deposited over the entire surface of each optical component. This coating may be applied by using electron beam evaporation, sputtering, chemical vapor deposition, or other similar processes in a memor [0021] The foregoing discloses and describes merely exemplary embodiments of the present invention. One skilled in the art will readily recognize from such discus20 .

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sion, and from the accompanying drawings and claims, that various changes, modifications and variations can be made therein without departing from the spirit and scope of the present invention.

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1. A method for fabricating a micro-optical component, comprising the steps of the steps of the steps.

More Carty De Co olitin consideration an etch stop layer onto a semiconhing ductor(substrate;), (O(HO)(O(HO) TMH) besit depositing, an contical component layer onto said etch stop layer; Dem Dem 114 here a sup coating said optical component layer with a to get of resist material; to periodically panier pniylapplying a mask to said photoresist material on note said optical component layer, ovideles i selectively etching away said optical compos ponent layer to form at least one optical column; forming a pedestal for each of said optical colyumns by selectively etching away, said etch orno stop layer; and origin) bus oimord or cipolishing each of said optical columns, thereby HO forming monolithic optical components

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columns prior to polishing said optical columns, and/or an telescotorid biss privomed depositing an antireflectivity coating onto each to a said optical components to maximize trans-

Imitted light; and/or wherein to the bias at least one of said optical components being oselected from the group consisting of a spherical ball lens, a cylindrical ball lens, a convex lens, a concave lens and a

contextism, and/or the ne growings to gets entraces and context of the context of

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and/or ("M_{c/S}) obintin nones bus said optical components layer comprises a said optical components layer comprises a said etch stop layer being comprised of a material selected from the group consisting of indium gallium arsenide phosphide (InGaAsP) and aluminum gallium, arsenide (AIGaAs),

no tand/ofeth level in war gonou labago iumetine said etch stop layer comprises,a layer at least 2

microns thick; and/or wo wanted use tao the step of selectively etching away said optical component layer further comprises dry etching in the areas surrounding said photoresist mask to form at least one optical column using at least one of electron scyclotron resonance (ECR) etching, inductive couple plasma (ICP) etching and reactive ion etching (RIE), and/or said etch stop layer being comprised of a quaternary semiconductor material and the step of forming a pedestal further comprises applying a selective quaternary etch to said etch stop laver, and/or the step of polishing further comprises selectively, wet etching the surface of said opticalcomponents at a temperature in the order of to pn10 to 20 degrees centigrade. etceles lan

3. , A method of fabricating micro-contical components on a semiconductor substrate comprising the steps of:

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said etch stop layer comorises a layer al teast scomponent substrate of coating as estate of coating as estate of coating as estate of coating as estate of coating captical score of layer onto sist material scleened layer layer layer and producing spide of layer and producing as estate and producing as mass solutions and producing as the solution of the coating components for more coating solutions and producing as the coating coating as a coating solutions are coating as a coa

layer with the layer of photoresist material; exposing the surface of said optical component exposing the surface of said optical component is a photoresist material to a photoresist material to a photoresist mask to form; at the least one optical photoresist mask to form; at the least one optical column; stand entring photoresist mask to some optical (9.33)

layer on the surface of said optical component

forming a pedestal for each of said optical collisitions by applying a selective etch to said etch to said etch stop layering monarch and reval the nondrino point removing said photoresist mask and cleaning nog the exposed surface of said optical columns; has and a cellocate of said optical columns and a cellocate of said optical columns that and a cellocate of said optical columns of the engage.

paratical state and hydrogen (Ar/CH_H/H₂), methon of self-indical configuration of the self-indical confi

¿The methodof Claim 3 further comprising the step
of applying an antireflectivity coating onto each of
said optical components (to maximize transmitted
light, and/or wherein one nodice ship offersed

at least one of said optical components being selected from the group consisting of a spheri-

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cal ball lens, a cylindrical ball lens, a conical consequence ball lens, a conical lens and a concave lens and a concave lens and a concave lens and a

said optical components and said substrate being comprised of material having substanitally similar thermal expansion coefficients for improving optical alignment, and/or

said optical components layer and said substrate being comprised of a material selected from the group consisting of indium phosphide (InP), gallium arsenide (InAs) and gallium phosphide (GaP), and/or

said optical components layer comprises a layer at least 20 microns thick, and/or

rial selected from the group comprised of a material selected from the group consisting of indium gallium arsenide phosphide (InGaAsP), and aluminum gallium arsenide (AlinAs), and aluminum gallium arsenide (AlGaAs), and/or

said etch stop layer comprises a layer at least 2

the step of coating said optical component
layer further comprises providing said photoresist material selected from the group consisting
thin of 2-ethoxyethylacetate 4 n-butyl acetate in
xylene and hexamethyldisilozane (HDMS), 2lethoxyethylacetate 4 n-butyl acetate in xylene
solvent, 2-ethoxyethylacetate 4 n-butyl acetate
lin xylene and silicon dioxide (SiO2) precoated,
2-ethoxyethylacetate 14 n-butyl acetate in
lin xylene and silicon nitride (Si3N₄) precoated, silicon dioxide (SiO2) and complex silicon nitride
(SixN₂), and complex silicon nitride
(SixN₂), and complex silicon nitride
(SixN₂), and complex silicon nitride

the step of selectively etching away said optical component layer further comprises dry etching in the areas surrounding said photoresist mask to form at least one optical column using at least one of electron cyclotron resonance (ECR) etching, inductive couple plasma (ICP) Etching and reactive-ion etching (RIE), and/or the step of selectively etching away said optical component layer further comprises using a dry *** etch mixture selected from the group consisting ு ுof/arˈgonˈˈandˈhiydrochloric acid/(Ar/HCl);ˈlargon hydrogen and chlorine (Ar/Cl2/H2), argon and hiydrobromic acid (Ar/Hbr), argon and bromine (Ar/Br₂), argon and chlorine (Ar/Cl₂), argon and methane and hydrogen (Ar/CH₄/H₂), methyl ਕੜਾਣ iodide (H3Cl) promine iodide (lbr3), "methane and hydrogen and sulfur flouride (CH₄/H₂/SF₆), The tempth inclide (C_2H_5I) , is one this produce (C_3H_7I) , hexaflouride carbon and hydrogen (C₂F₆/H₂), and dichlorodifluoro carbon and oxygen emec(@OIgFg/Og),pand/or- blee to had to dethe step of forming a pedestal further comprises using a selective wet etching material selected from the group consisting of potassium hydroxyde:potassium ferricyanide:deionized water (KOH: K3Fe(CN)6:H2O), lactic acid:nitric acid (CH₃CH₂OCOOH:HNO₃), hydrochloric acid:nitric acid (HCI:HNO3), phosphoric acid:hydrogen peroxide:deionized water (H₃PO₄:H₂O₂:H₂O), nitric acid (HNO₃); sulfuric acid:hydrogen peroxide:deionized all water (H2SO4:H2O2:H2O), nitric acid:deionized in total unto its perhaps water (HNO3:HOOC(CH2O)2COOH:H2O) のかい and hydroflüöric acid:hydrogen peroxide:deionized water (HF:H2O2:H2O), and/order to a design water

'said etch stop layer being comprised of a quaternary semiconductor material and the step of forming a pedestal further comprises applying a selective quaternary etch to said etch stop layer, and/or sayer middle viewtoelse

the step of polishing further comprises using a selective wet polishing solution selected from the group consisting of hydrofloric acid hydrobromic acid (HE:10 HBr), hydrobromic acid: acid: acid: (HBr:CH; COOH) hydrochloric acid: propylene glycol (HC:CH; CHOHCH; CHOHCH;

the step of applying an antireflectivity coating further comprises using a coating process selected from the group consisting of electron beam evaporation, sputtering and chemical vapor deposition, and/or antireflectivity coating the step of applying an antireflectivity coating further comprises depositing at least one layer sium fluoride (MgF) coating containing magnesium fluoride (MgF) alluminum oxide (Al2O3), and silicon nitride (SiaNa).

A micro-optical system for optical signal processing, comprising max of security and does not comprising to the comprising of the comprisi

a semiconductor substrate; multispin entra an optical component being formed from an epitaxial optical component layer deposited on said substrate; and was exclusive to be

a pedestal coupling said optical component to said substrate being formed from a stop etch layer, said stop etch layer being interposed between said optical component layer and said substrate.

6. The micro-optical system of Claim 5 wherein

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said optical component being selected from the group consisting of a spherical ball lens, a cylindrical ball lens, a conical ball lens, a convex lens, a concave lens and a prism, and/or said optical components and said substrate being comprised of material having substantially similar thermal expansion coefficients for -15. improving optical alignment, and/or said optical components layer and said substrate being comprised of a material selected from the group consisting of indium phosphide (InP), gallium arsenide (GaAs), indium arsenide (InAs) and gallium phosphide (GaP), and/or said optical components layer comprises a layer at least 20 microns thick, and/or said etch stop layer being comprised of a material selected from the group consisting of indium gallium arsenide phosphide (InGaAsP), aluminum gallium arsenide (AlGaAs), and Indium Gallium Arsenide (InGaAs), and/or said etch stop layer comprises a layer at least 2 30 - microns thick.

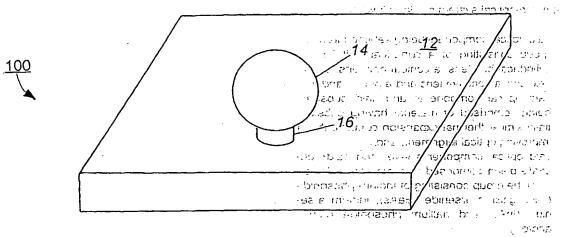
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Figure 1

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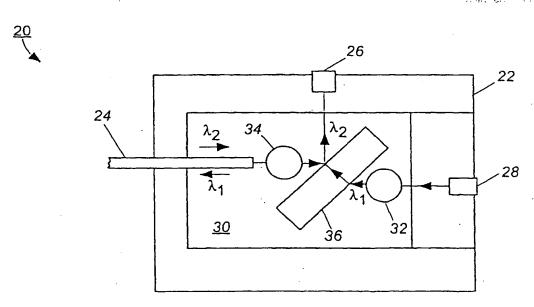


Figure 2

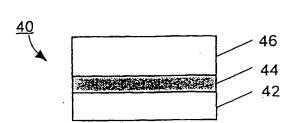


Figure 3

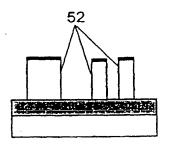


Figure 6

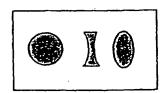


Figure 4

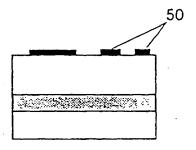


Figure 5

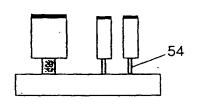


Figure 7

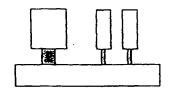


Figure 8

